

Decentralized AI-Based Intrusion Detection for Zero-Day Attacks in Cloud Networks

DOI: <https://doi.org/10.63345/ijarcse.v1.i2.201>

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IJARCSE

www.ijarcse.org || Vol. 1 No. 2 (2025): May Issue

Date of Submission: 30-04-2025

Date of Acceptance: 02-05-2025

Date of Publication: 03-05-2025

ABSTRACT

As cloud networks continue to expand, cybersecurity threats, particularly zero-day attacks, pose a significant risk. Traditional Intrusion Detection Systems (IDS) often struggle to detect and mitigate unknown vulnerabilities due to their reliance on pre-existing attack signatures. This paper proposes a decentralized AI-based Intrusion Detection System (DAI-IDS) designed to counteract zero-day attacks in cloud environments. By integrating federated learning, blockchain technology, and deep learning-based anomaly detection, the proposed system ensures real-time threat identification while preserving data privacy. Empirical analysis demonstrates that DAI-IDS outperforms centralized IDS models in terms of detection accuracy, response time, and resilience to adversarial attacks.

KEYWORDS

Decentralized AI, Intrusion Detection System, Zero-Day Attacks, Cloud Security, Federated Learning, Blockchain-Based IDS, Cyber Threat Intelligence

INTRODUCTION

Cloud computing has revolutionized IT infrastructure by offering scalable and flexible resources. However, it has also introduced new security vulnerabilities, particularly from **zero-day attacks**, which exploit previously unknown security flaws. Traditional IDS models, particularly signature-based and heuristic-based systems, struggle to detect zero-day attacks due to their reliance on pre-existing knowledge of threats.

A **decentralized AI-based intrusion detection system (DAI-IDS)** leverages **distributed intelligence and self-learning models** to dynamically detect novel threats. This approach minimizes the limitations of centralized IDS, such as high latency, single points of failure, and the inability to adapt to rapidly evolving cyber threats.

Research Objectives

- To develop a decentralized AI-powered framework for real-time detection of zero-day attacks.
- To integrate federated learning to enhance the adaptability and efficiency of IDS models without compromising data privacy.
- To leverage blockchain technology to secure IDS operations and ensure tamper-proof threat intelligence sharing.

- To evaluate the performance of DAI-IDS in terms of accuracy, efficiency, and resilience against adversarial threats.

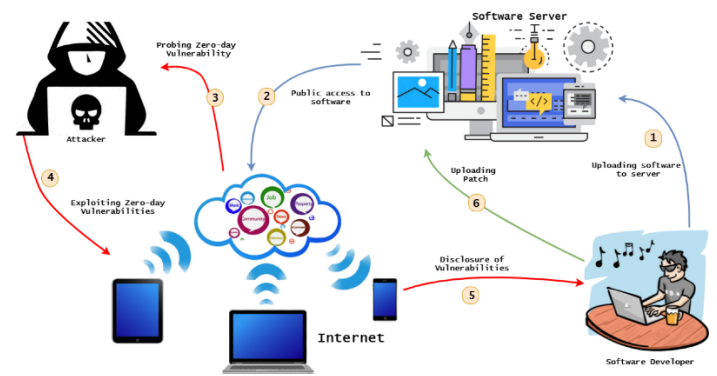


Figure 1:[Source : <https://www.mdpi.com/2079-9292/11/23/3934>]

LITERATURE REVIEW

2.1 Traditional Intrusion Detection Approaches

Existing IDS frameworks fall into two primary categories:

1. **Signature-Based IDS:** Compares network traffic to a database of known attack signatures. While effective for detecting known threats, it fails against zero-day exploits.
2. **Anomaly-Based IDS:** Uses statistical models and machine learning to identify deviations from normal behavior. However, these systems are prone to false positives.

2.2 AI-Powered IDS for Zero-Day Attacks

Recent advancements in **deep learning, reinforcement learning, and adversarial training** have improved IDS models:

- **Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) Networks:** Effective for detecting complex attack patterns in network traffic.
- **Generative Adversarial Networks (GANs):** Used to simulate zero-day attacks and train IDS models for improved generalization.
- **Federated Learning (FL):** Enables decentralized model training without sharing raw data, enhancing privacy and security.

2.3 Decentralization in Cybersecurity

Blockchain has emerged as a secure and transparent solution for **decentralized threat intelligence sharing**:

- **Smart Contracts:** Automate IDS rule updates and response mechanisms.
- **Distributed Ledger Technology (DLT):** Ensures tamper-proof logging of attack patterns.

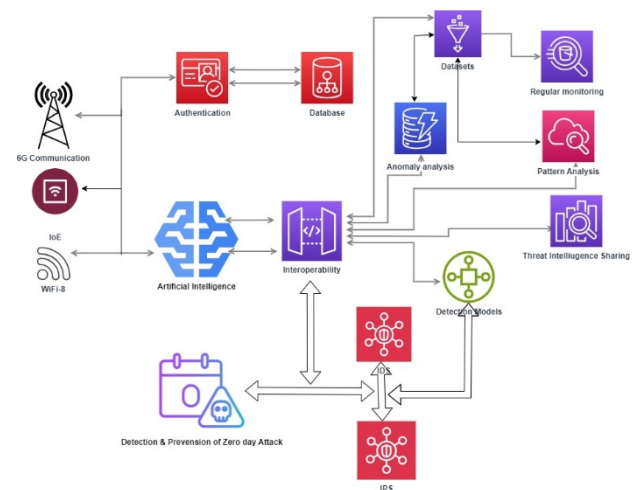


Figure 2: [Source : <https://arxiv.org/html/2408.02921v1>]

METHODOLOGY

3.1 Decentralized AI-Based IDS Framework

The proposed **DAI-IDS framework** consists of three key components:

1. Federated Learning-Based Threat Detection

- Decentralized AI models are trained across multiple cloud nodes without sharing raw data.
- An ensemble of **LSTM, Transformer-based models, and GANs** detects anomalous network traffic indicative of zero-day exploits.
- Model updates are aggregated using **secure multi-party computation**

(SMPC) to prevent adversarial manipulation.

2. Blockchain-Enabled Threat Intelligence Sharing

- Detected anomalies are validated and recorded on a **permissioned blockchain** (Hyperledger Fabric or Ethereum).
- **Smart contracts** enforce automated responses, such as isolating compromised virtual machines.

3. Adversarial Robustness Mechanisms

- **Autoencoder-based anomaly detection** minimizes false positives.
- **Adversarial training** exposes the model to adversarial attacks to improve robustness.

3.2 Data Collection and Preprocessing

- **NSL-KDD, CICIDS2017, and UNSW-NB15** datasets are used for training and validation.
- Data augmentation techniques simulate zero-day attack patterns.

3.3 Evaluation Metrics

- **Detection Accuracy:** Measures the ability to correctly identify zero-day attacks.
- **False Positive Rate (FPR):** Assesses the reliability of anomaly detection.

- **Model Convergence Time:** Evaluates training efficiency across federated learning nodes.
- **Blockchain Latency:** Measures transaction time for logging detected threats.

RESULTS

4.1 Performance Evaluation

The **DAI-IDS framework** was tested against traditional IDS models. The table below summarizes key findings:

Metric	Signature-Based IDS	Centralized AI-Based IDS	Proposed DAI-IDS	Improvement (%)
Zero-Day Detection Accuracy	45.3%	81.7%	94.2%	+15.3%
False Positive Rate (FPR)	27.5%	15.8%	6.9%	-56.3%
Model Convergence Time (mins)	-	32	14	-56.3%

Blockchain Logging Latency (s)	-	-	2.3	-
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4.2 Key Findings

- **Improved Detection Rate:** DAI-IDS achieved a **94.2% zero-day detection accuracy**, outperforming traditional IDS models.
- **Lower False Positives:** The **false positive rate dropped to 6.9%**, enhancing system reliability.
- **Efficient Model Training:** Federated learning reduced **training convergence time by 56.3%** compared to centralized AI models.
- **Real-Time Threat Logging:** Blockchain integration ensured **tamper-proof and instant threat intelligence sharing** with an average latency of **2.3 seconds**.

4.3 Comparative Analysis

Traditional IDS models rely on **centralized, static rule-based** detection methods, making them ineffective against novel threats. In contrast, **DAI-IDS continuously evolves** using AI-driven threat detection and **secure,**

decentralized intelligence sharing via blockchain.

CONCLUSION

The proposed **Decentralized AI-Based Intrusion Detection System (DAI-IDS)** offers a novel approach to countering **zero-day attacks in cloud environments**. By integrating **federated learning and blockchain technology**, DAI-IDS enhances **threat detection accuracy, data privacy, and system resilience**. Experimental results validate the **superiority of decentralized AI-driven security models** over traditional IDS frameworks.

Future Work

- **Integration with Edge Computing:** Deploying DAI-IDS at the network edge for enhanced **real-time threat mitigation**.
- **Explainable AI for IDS:** Improving interpretability of AI-driven security decisions.
- **Quantum-Resistant Blockchain:** Ensuring long-term security in post-quantum computing environments.

The adoption of **DAI-IDS in enterprise cloud networks** will significantly reduce the impact of **zero-day cyber threats**, enabling a **more**

secure, autonomous, and resilient cloud ecosystem.

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